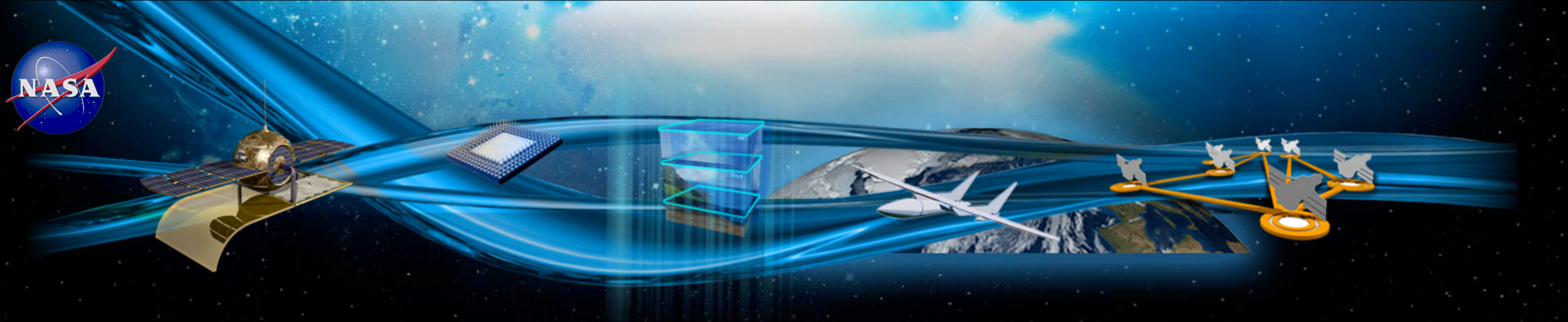


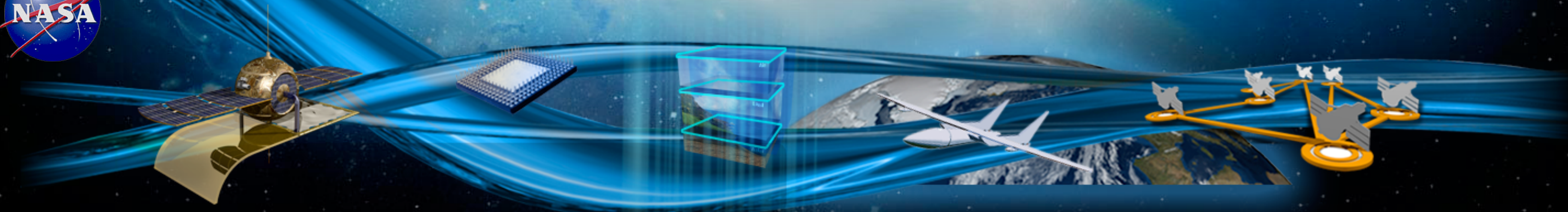
ESTO Investments in Advanced Information Technology: Opportunities and Future Directions

Michael Seablom, Program Manager

[†]Earth Science Technology Office - Earth Science Division
NASA Headquarters

December 18, 2013

Overview of the Earth Science Division



Overarching goal: to advance Earth System science, ***including climate studies***, through spaceborne data acquisition, research and analysis, and predictive modeling

Six major activities:

- Building and operating Earth observing satellite missions, many with international and interagency partners
- Making high-quality data products available to the broad science community
- Conducting and sponsoring cutting-edge research
  - Field campaigns to complement satellite measurements
  - Analyses of non-NASA mission data
  - Modeling
- Applied Science – developing and demonstrating applications that deliver societal benefit
- Developing technologies to improve Earth observation capabilities
- Education and Public Outreach

The NASA Science Portfolio

Science Mission Directorate

- **Earth Science Division**
- Heliophysics Division
- Astrophysics Division
- Planetary Sciences Division

Research

Atmospheric Composition
Ecosystems
Land Cover / Land Use
Biological Oceanography and Biodiversity
Solid Earth
Modeling, Analysis, Prediction
High End Computing

Flight

Program management of current & planned satellite missions (Tier I & II Decadal Survey missions; Climate Continuity missions)
Earth Science Data Systems

Applied Sciences

Health & Air Quality
Water Resources
Disasters
Ecosystems

Technology

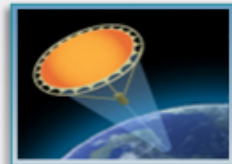
Advanced Information Systems Technology Program
Instrument Incubator Program
Advanced Component Technology Program
In-Space Validation of Earth Science Technologies

ESTO
Earth Science Technology Office

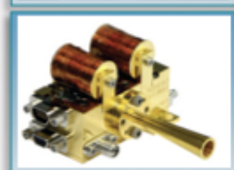
Earth Science Technology Program Overview

NASA's Earth Science Technology Office (ESTO) is a ***targeted, science-driven, competed, actively managed, and dynamically communicated technology program*** and serves as a model for technology development. Competitive, peer-reviewed proposals enable selection of best-of-class technology investments that ***retire risk*** before major dollars are invested: a cost-effective approach to technology development and validation. ESTO investment elements include:

Observation



Instrument Incubator Program
Provides robust new instruments and measurement techniques
TRL 3-6; 18 active projects



Advanced Component Technology Program
Provides critical components and subsystems for instruments and platforms
TRL 2-6; 15 active projects

Information

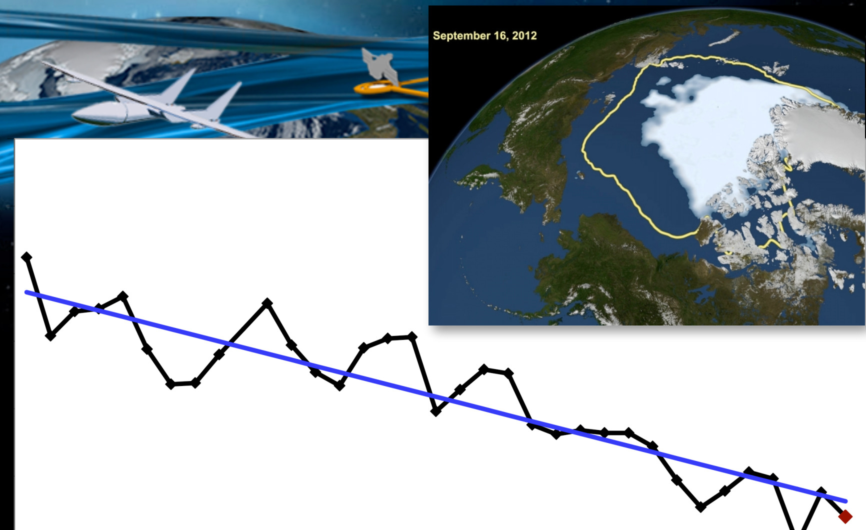
Advanced Information System Technology Program
Provides innovative on-orbit and ground capabilities for collecting, processing, and managing remotely-sensed data and generation of data products; TRL 2-6; 22 projects

Validation

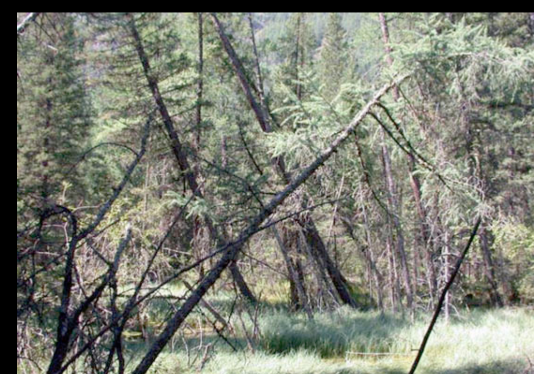
In-Space Validation of Earth Science Technologies (InVEST)
Provides in-space, orbital technology validation and risk reduction for small instruments and components in lieu of ground/aircraft testing; TRL 5-7; 3 projects

A Focus on Climate Change

10,000 Years of Ice Gone in 1 Month:
Collapse of the Larsen B Ice Shelf



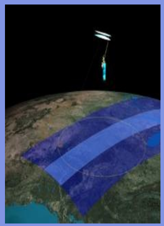
Loss of nearly 2 million square kilometers of Arctic sea ice since 1978



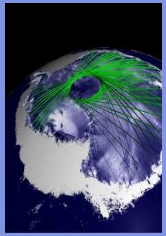
Permaforst - "Drunken Forest"

Methane chimneys appearing in frozen lakes; “drunken” houses and trees in the melting permafrost

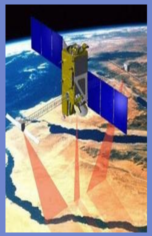
Initial Strategy for Climate Missions…



Soil Moisture Active Passive **(SMAP)**

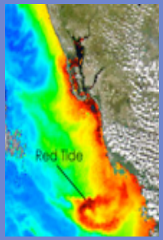


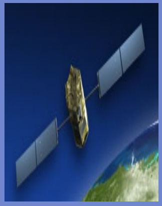
Ice, Cloud, and land Elevation Satellite II **(ICESat-II)**



Surface Water and Ocean Topography **(SWOT)**

Pre-Aerosol - Cloud - Ecosystems ***(PACE)***





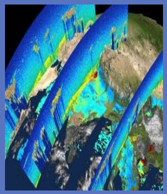
Active Sensing of CO2 Emissions **(ASCENDS)**

Hyperspectral Infrared Imager **(HYSPIRI)**

Geostationary Coastal and Air Pollution Events **(GEO-CAPE)**

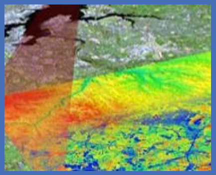
Deformation, Ecosystem Structure and Dynamics of Ice (Radar) **(DESDynI -R)**

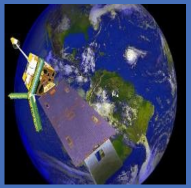
Climate Absolute Radiance and Refractivity Observatory **(CLARREO)**



Aerosol - Cloud - Ecosystems **(ACE)**

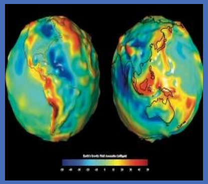
LIDAR Surface Topography **(LIST)**





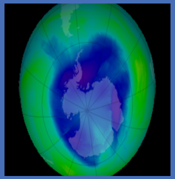
Precipitation and All-Weather Temperature and Humidity **(PATH)**

Gravity Recovery and Climate Experiment - II **(GRACE - II)**

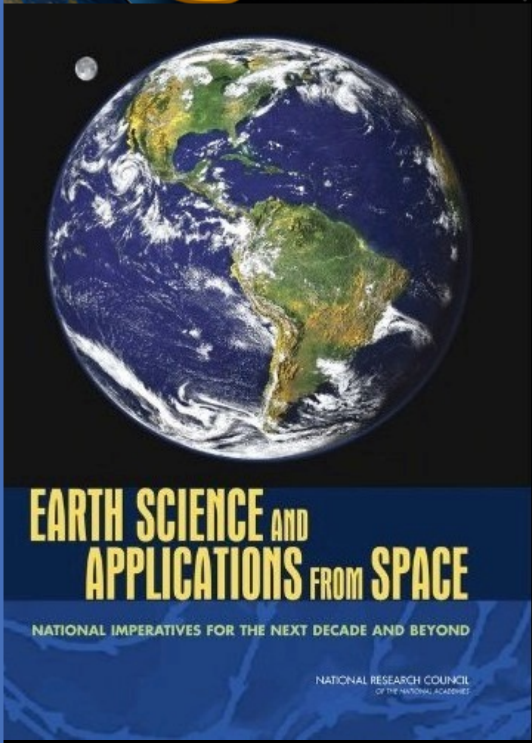


Snow and Cold Land Processes **(SCLP)**

Global Atmospheric Composition Mission **(GACM)**

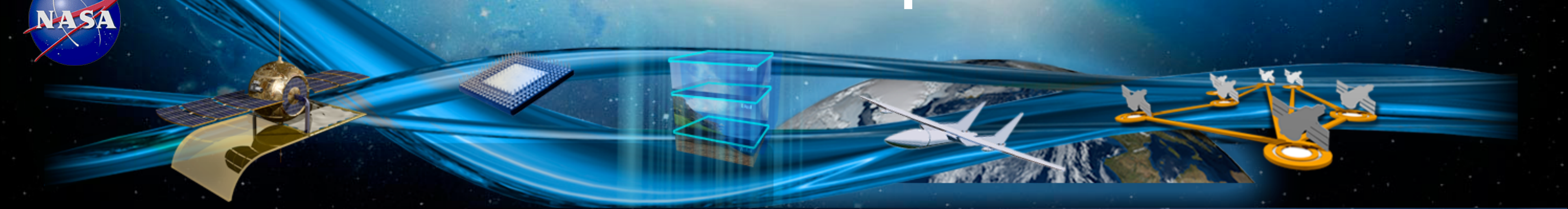


Three-Dimensional Winds from Space Lidar **(3D-Winds)**



2007 NRC Decadal Survey

… and the current Implementation Plan



Responding to the Challenge of Climate and Environmental Change:

NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space

June 2010

Planned Missions (2013-2023)

The Role of Information Technology

What “is” Information Technology?

“The application of computers and telecommunications equipment to store, retrieve, transmit, and manipulate data”
— *A Dictionary of Physics, Oxford University Press.*

Proposed definition of “Advanced Information Technology”:

“New, more capable, and more complex applications of computers and telecommunications equipment to store, retrieve, transmit, and manipulate data, when compared to industry standards.”

The NASA Center-Level Enterprise View

Mission Objectives / Science Goals

Projects

Data → Information → Knowledge
Data processed from user / project applications and used for scientific research.

User / Project Applications
Flight Software, Science data analysis, numerical algorithms, etc.

Project Technical Infrastructure
Networks, communication, capital equipment, high performance systems, local clusters, etc.

Managed by Projects

Project IT Layer built atop Institutional IT layer

Institution

Data → Information → Knowledge
Data collected from core business applications used for managerial decisions.

Core Business Applications
Business Warehouse, Human Capital Management, Payroll, Procurement, Travel, Property Management, etc.

Institutional Technical Infrastructure
Networks, communication, capital equipment, etc.

Managed by Institutions

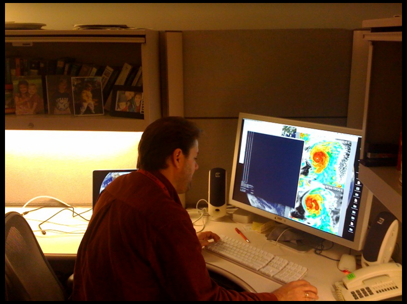
IT Security, External Comm Perimeter

The Full Cost of Science Research & Analysis

Source: Chris Lynnes & Greg Leptoukh, NASA/GSFC

Earth Science Technology Office

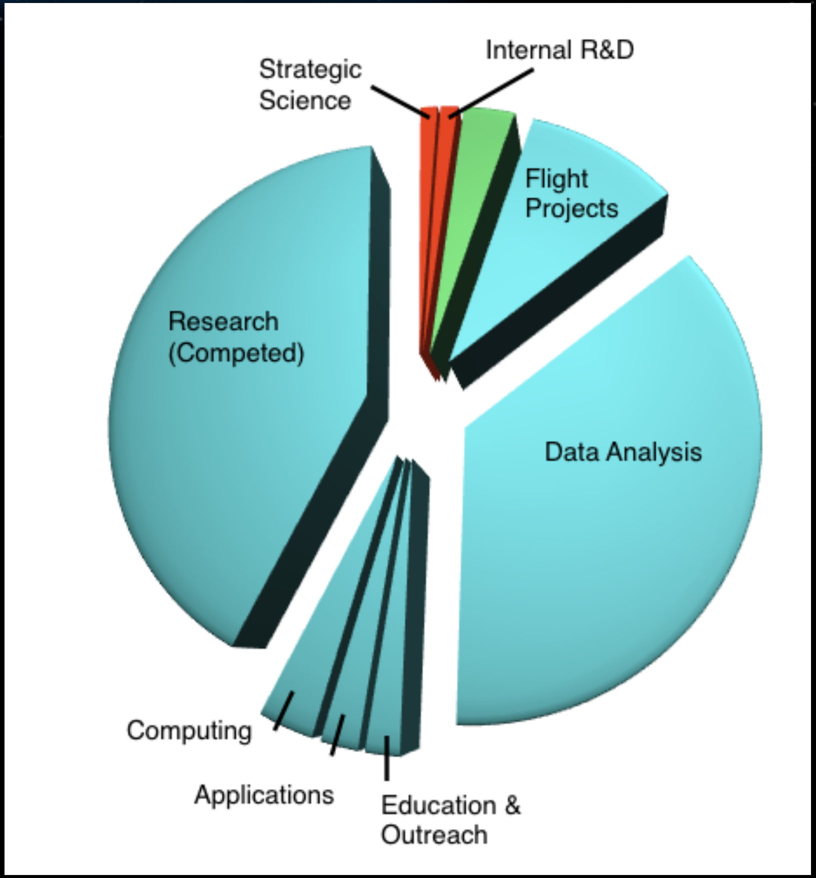
Goddard's Earth Science Division



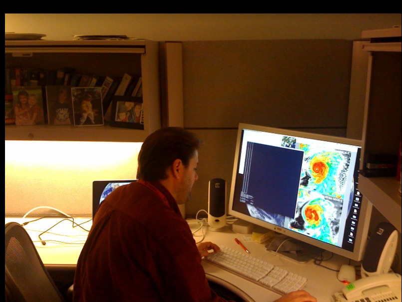
2009 Profile

195 Civil Servants
215 University Affiliates
639 Contractors

Estimated budget: $177M



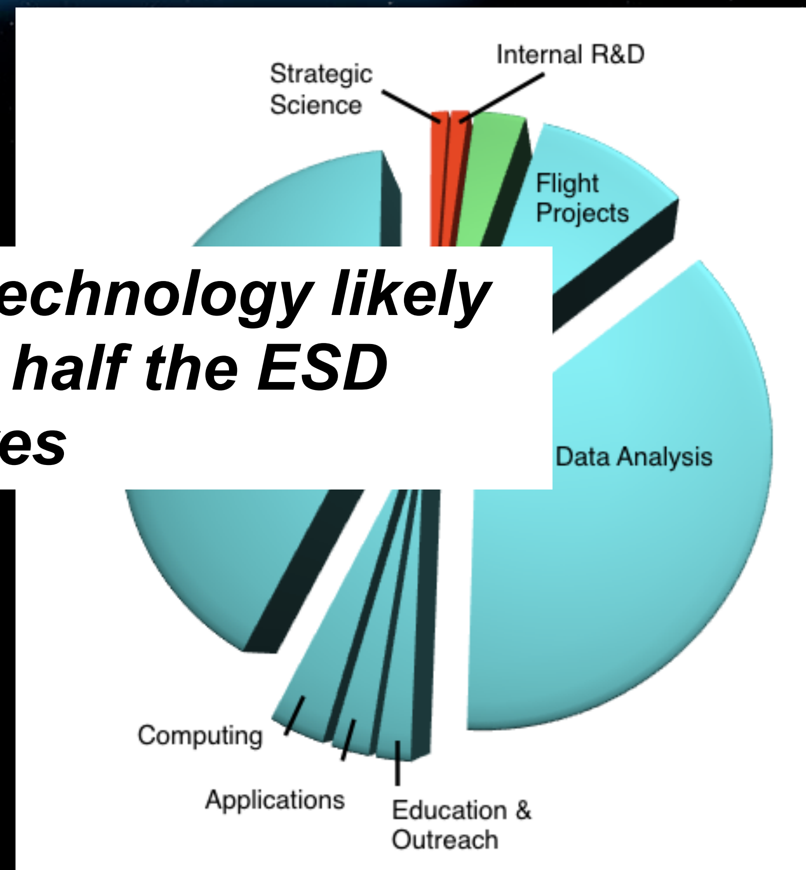
Goddard's Earth Science Division



2009 Profile

Takeaway: Information Technology likely consumes more than half the ESD expenditures

Estimated budget: $177M

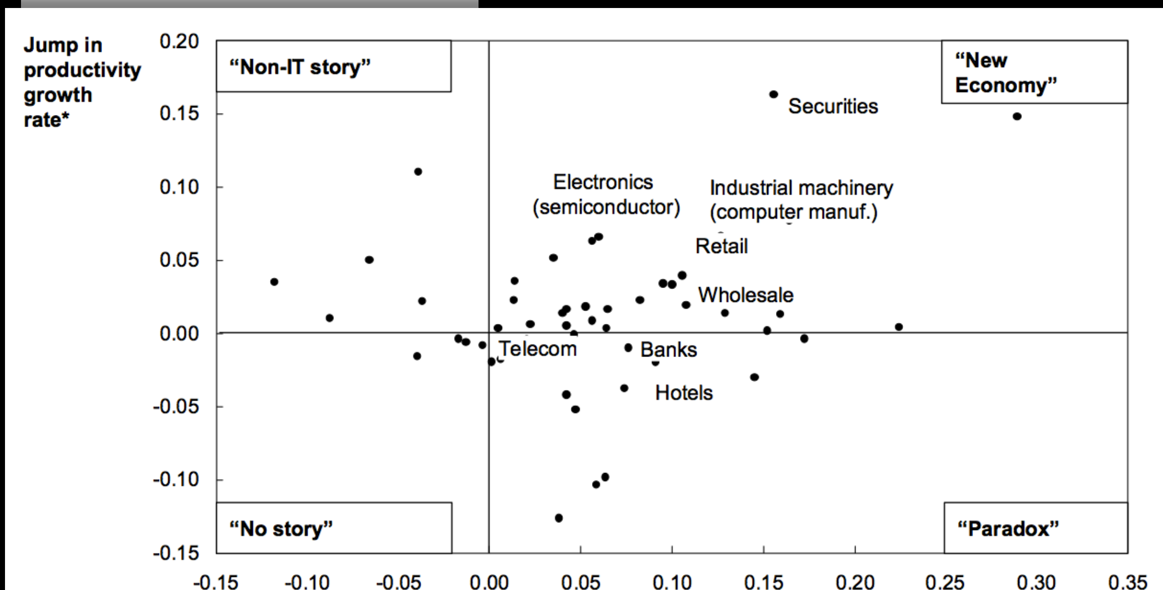


Is Information Technology "Important" ?


Harvard Business Review
www.hbrreprints.org
HBR AT LARGE
As information technology's power and ubiquity have grown, its strategic importance has diminished. The way you approach IT investment and management will need to change dramatically.
IT Doesn't Matter
by Nicholas G. Carr
With Letters to the Editor

Information Technology is a *major* cost driver within programs of the Science Mission Directorate!

So why would Nick Carr's seminal paper "IT Doesn't Matter" seem to imply the opposite? (Hint: Beware of articles with misleading titles).



McKinsey Global Institute analysis, 2001

Carr actually states:

- IT has become a commodity - businesses no longer gain a strategic advantage through heavy investments in IT
- Spend less on IT and delay IT investments whenever possible (let others experiment with the cutting edge)

Is Information Technology "Important" ?

During era of high investments in IT (2001), McKinsey study identified key characteristics of productivity improvements due to IT:

Information technology is important to productivity growth, but only in the context of a broader set of managerial decisions.

The study found that productive IT applications tended to share 3 characteristics:

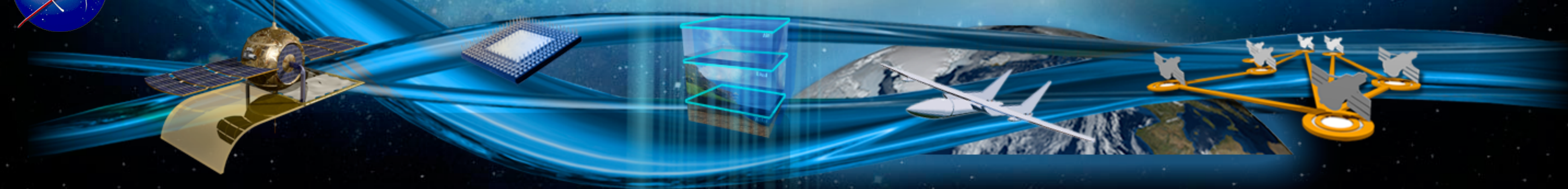
1. the applications were tailored to sector-specific business processes and linked to key performance metrics

2. they were deployed in a sequence that built capabilities over time

3. they co-evolved with managerial and technical innovation to change business processes for the creation of new products and services

This is the basis for the management of information technology!

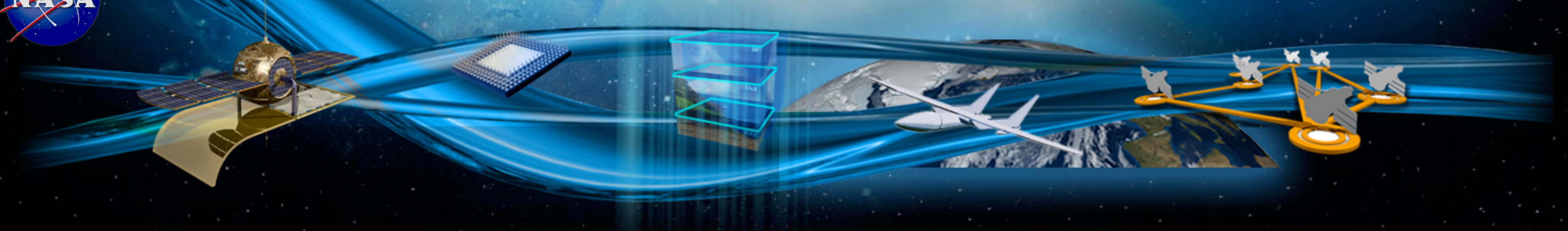
CIO-level Innovation Program



NASA Information Technology Labs is a CIO-level competed activity to efficiently evaluate, adopt, and adapt emerging information technologies. Projects are short and focused (90 days to 1 year) and results are shared for broad adoption. Some examples:

- Collaboration established between Personal Identity Verification credential team and Google Apps for sharing data
- Johnson Space Center intranet search engine enhanced with capabilities from Wolfram Alpha
- Desktop standards team developed better security methods for mobile assets

Types of IT Investments



Continuous Improvement	Operational Transformation	Revolutionary Improvement
Evolutionary changes throughout the organization	Focused efforts that improve and leverage core processes	Complete reengineering and redefinition of the business

Continuous Improvement

- Generally low cost
- Available to most organizations
- Low to medium payoff

Operational Transformation

- Differentiating IT capabilities
- Substantial new products and/ or services
- Step change in efficiency
- High value and widely available

Revolutionary Improvement

- Generally high cost and risk
- High value in rare cases

“Core” (cost of doing business) ⟷ “Differentiating” (creating a competitive advantage)

McKinsey & Co., “How IT Enables Productivity Growth”

Types of IT Investments

Continuous Improvement
Evolutionary changes throughout the organization

Operational Transformation
Focused efforts that improve and leverage core processes

Revolutionary Improvement
Complete reengineering and redefinition of the business

Continuous Improvement:

- Generally low cost
- Available to most organizations
- Low to medium payoff

Operational Transformation:

- Differentiating IT capabilities
- Substantial new products and/ or services
- Step change in efficiency
- High value and widely available

Revolutionary Improvement:

- Generally high cost and risk
- High value in rare cases

CIO functions

IT Labs

ESD Data Systems

AIST

"Core" (cost of doing business) ⟷ "Differentiating" (creating a competitive advantage)

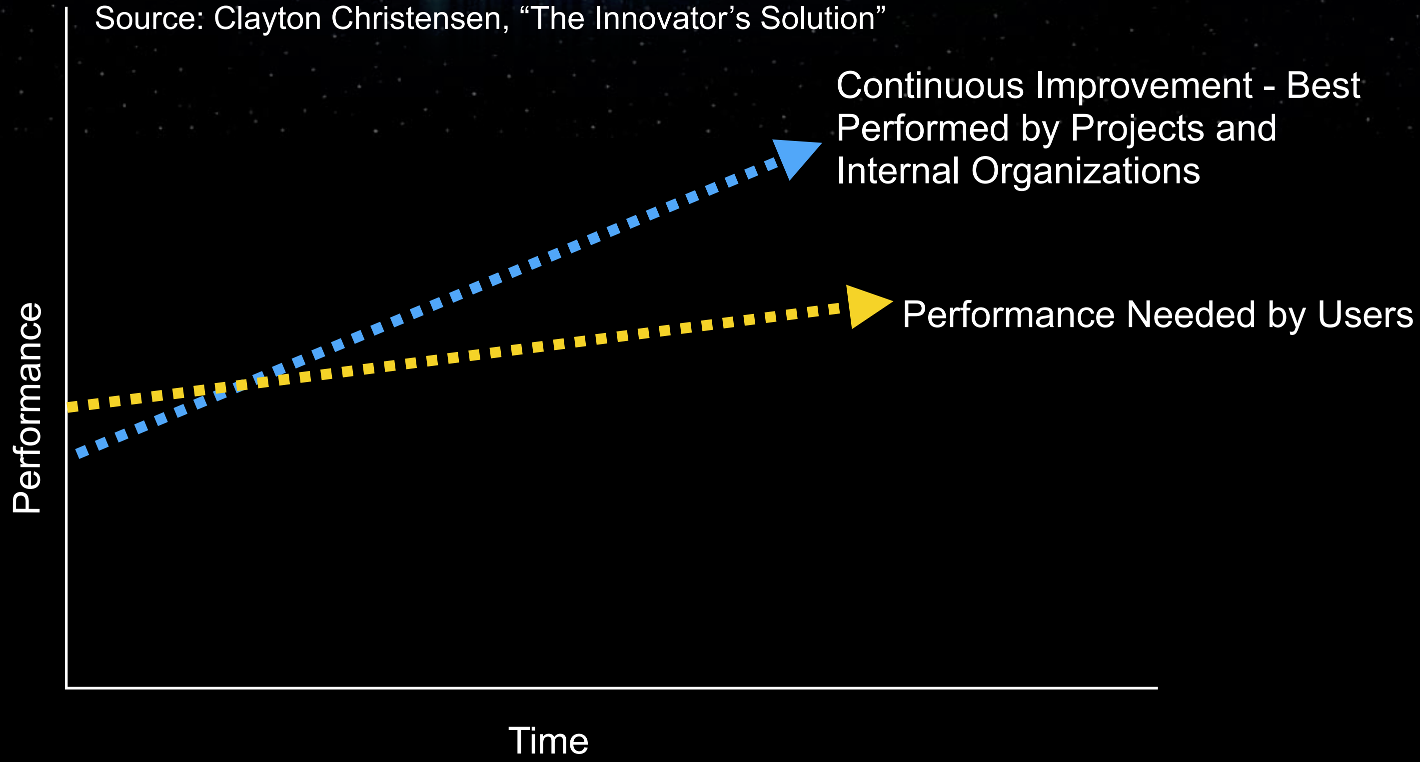
Project IT

High End Computing

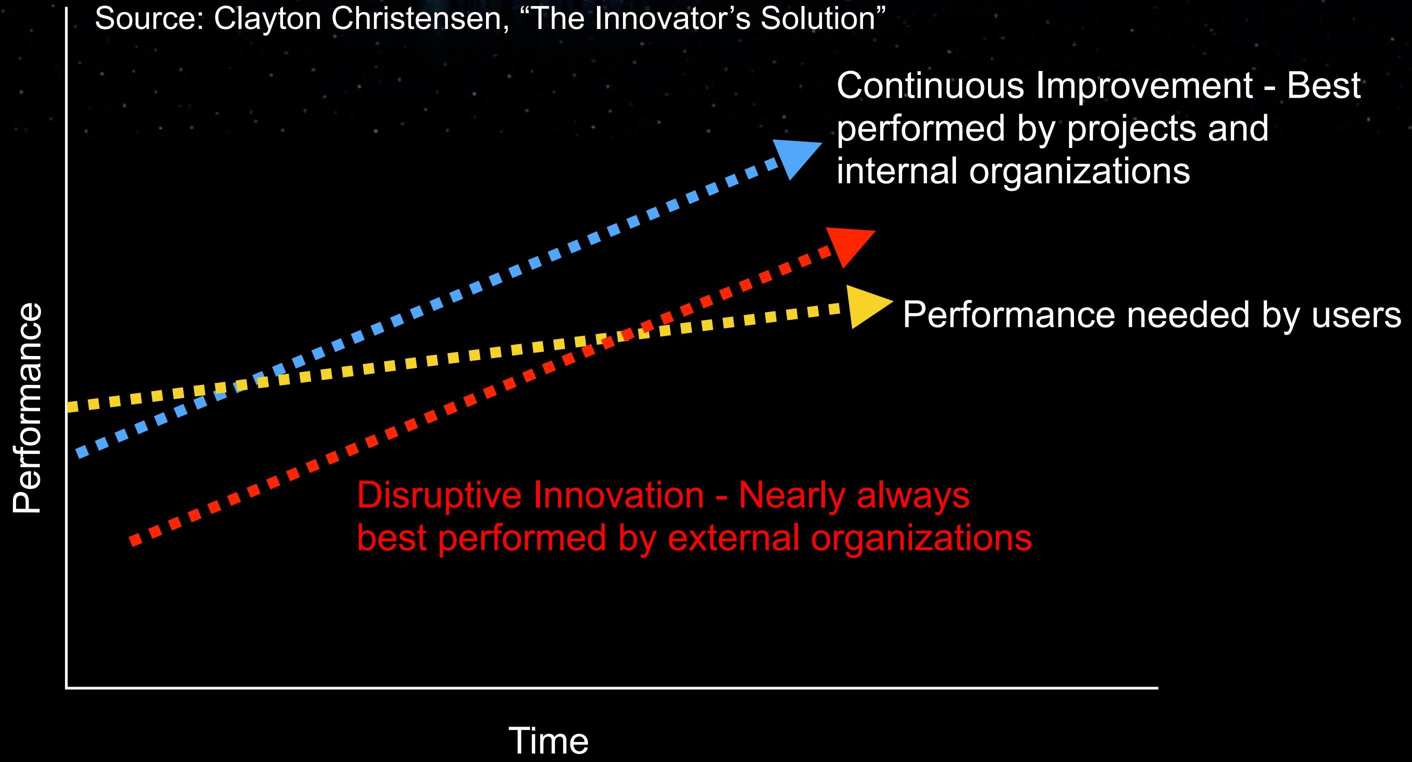
"Standard" Information Technology Investments

"Advanced" Information Technology Investments

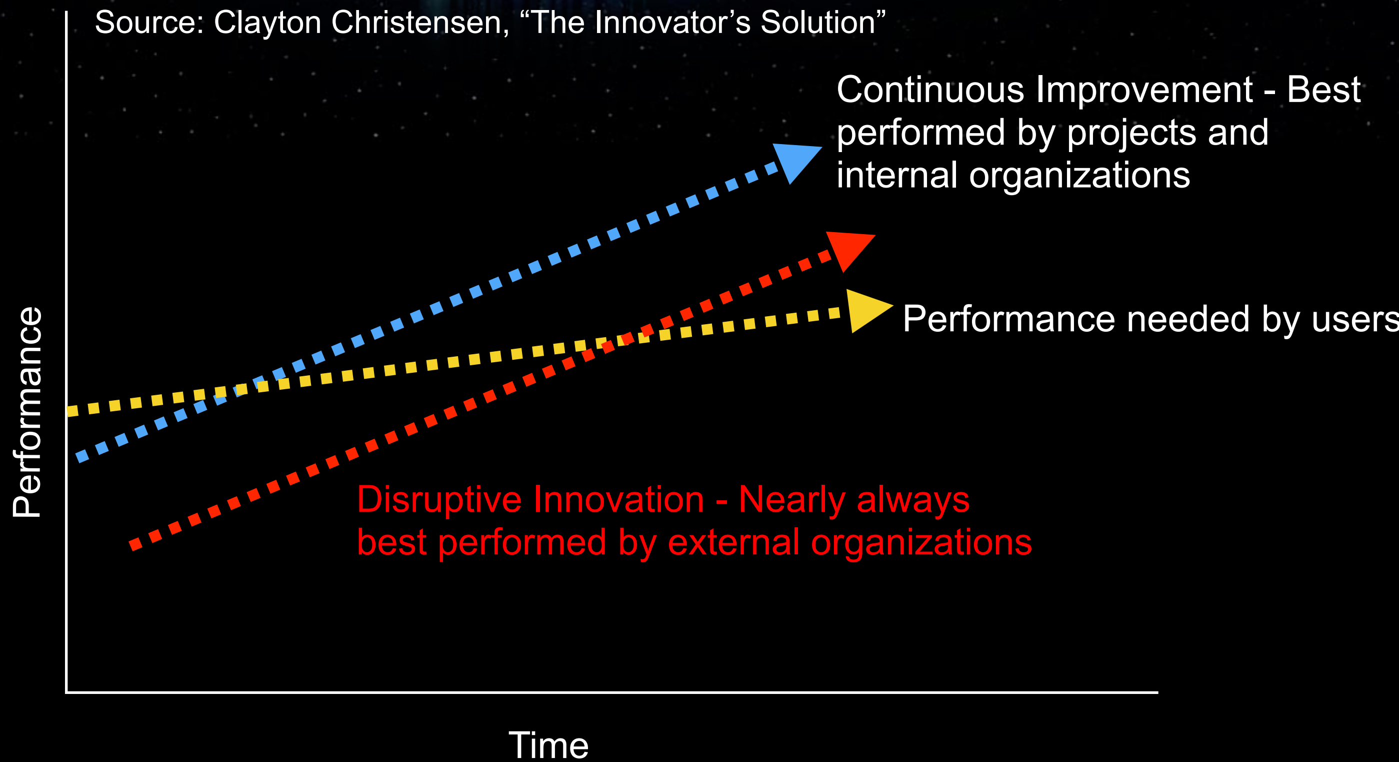
Also… “Disruptive” Technologies



Also… “Disruptive” Technologies



Also… "Disruptive" Technologies



Some Victims of Disruptive Technologies

Kodak: digital cameras disrupted a lucrative film business
Many newspapers: early online newspapers tried to extend their print businesses
Digital Equipment Corp (DEC): emphasized mid-sized computers and considered PCs "toys"

Disruptive Technologies - Takeaways

Some findings from Clayton Christensen, author of “The Innovator’s Dilemma”, include:

Be aware of the potential (threat) of disruptive technologies but don’t throw out the capabilities, organizational structures, and managerial techniques that have made you successful.

In an environment of potentially disruptive technologies:

Do *not* rely on your customers (users) — they cannot lead you to solutions which they perceive they do not need

Manage innovation wisely — provide fully the necessary resources to ensure successful projects

Don’t try to stretch or force a disruptive technology to fit current needs

Change the culture of the mainstream organization to take on higher risk projects in technology change OR *create a new organization*

Earth Science Information Systems - Value Chain

Data Collection & Handling → **Data & Information Production** → **System Management** → **Search, Access, Analysis, Display**

Earth Science Information Systems - Value Chain

Data Collection & Handling

Significantly improve on-board processing

Develop better fault handling

Promote standards for better reliability and interoperability of sensor hardware and software

Enable adaptive on-board science processing

Data & Information Production

Improve data quality via provenance, lineage, integrity, validation, accountability

Enable use of new data in numerical models while addressing issues of data quality

Develop new capabilities for data product and workflow management

Leverage semantic web technology for interoperability

System Management

Develop technologies to enable interoperability between data production, storage, archive, and analysis systems

Develop tools to enable space/ground data processing trades & real-time reconfiguration

Create extensible, evolvable frameworks for information processing

Enable goal-directed science management

Search, Access, Analysis, Display

Develop technologies to enable interoperability between data production, storage, archive, and analysis systems

Enable the use of service-oriented architectures

Improve techniques for real-time data deployment

Enhance knowledge management

Develop new techniques for visualization

ESTO advanced information technology investments create differentiating capabilities in every part of the value chain

ESTO's Information Technology Group

Mission Statement

Identify, develop, and demonstrate advanced information systems technologies (TRL 2-6) that reduce the risk, cost, size, and development time for Earth Science information systems, increase the accessibility and utility of science data, and enable new observations and information products.

Increase science value by responding to dynamic events using autonomy

Coordinate multiple observations for synergistic science

Improve interdisciplinary science production environments

Improve access, storage, and delivery of large data volumes

Improve system interoperability and use of standards

Decrease mission cost and risk through autonomy and automation

Solicitation History: Advanced Information System Technology (AIST)

AIST-02 Comms / On-Board Processing Focus → AIST-05 Sensor Web Focus → AIST-08 Sensor Web & Decadal Survey Focus → AIST-11 Multiple Focus Areas → CMAC-11* Cyber-infrastructure Focus

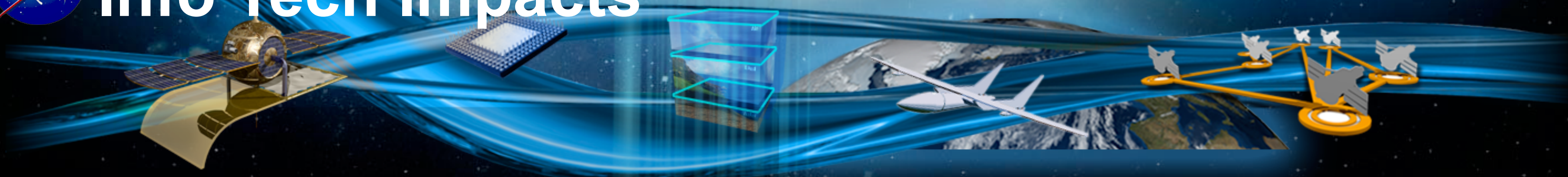
*Computational Modeling and Cyberinfrastructure (CMAC) program was solicited and managed by the High End Computing program; 1/3 funding provided by ESTO

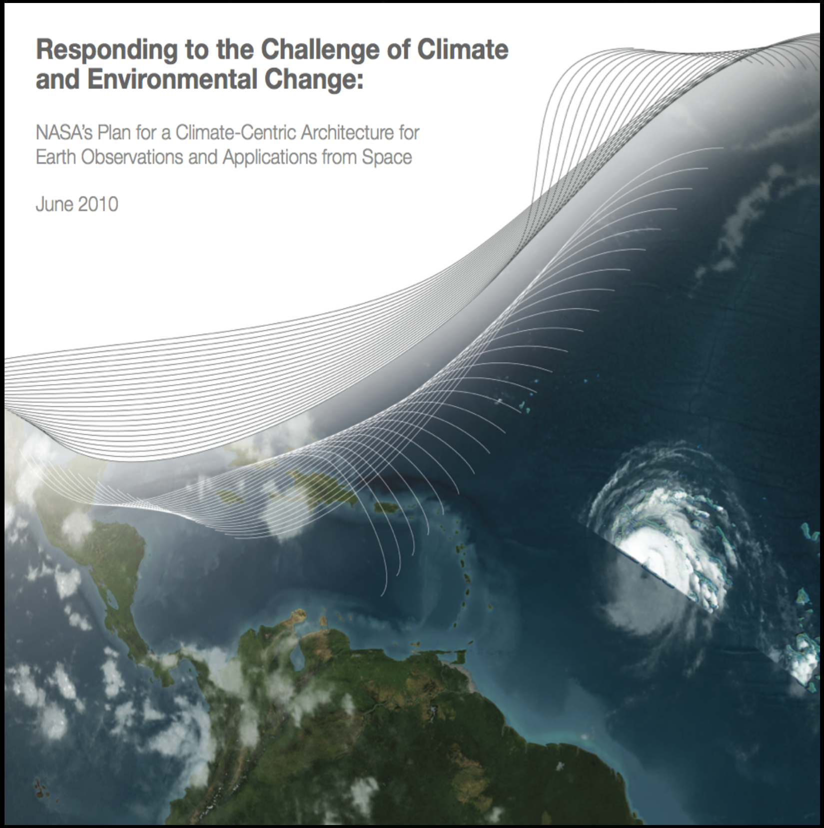
Examples of Projects

Data Collection & Handling	Data & Information Production	System Management	Search, Access, Analysis, Display
"Autonomous, On-board processing for sensor systems", *M. French / USC*	"Interactive mapping of plumes via GPU-based volumetric ray casting", *L. Berk, SSI, Inc.*	"Next-generation real time geodetic station sensor web for natural hazards", *Y. Bock / SIO*	"Moving objects database technology for weather event analysis & tracking", *M. Schneider / Univ. of Fla.*
"On-board processing to advance the PanFTS for GEOCAPE", P. *Pingree / JPL*	"Integration of CAMVis and Multiscale Analysis Package for tropical cyclone studies", *B. Shen / Univ. of Md.*	"EPOS for coordination of asynchronous sensor webs", *S. Kolitz/ Draper Labs*	"A unified simulator for Earth Remote Sensing", *S. Tanelli / JPL*
"High speed on-board data processing for science instruments (HOPS)", *J. Beyon, LaRC*	"Empowering cloud resolving models through GPU and asynchronous I/O", *W-K Tao, GSFC*	"Semi-automatic science workflow synthesis for high-end computing on the NASA Earth Exchange", *R. Nemani / ARC*	"Multivariate data fusion and uncertainty quantification for remote sensing", *A. Braverman / JPL*

ESTO
Earth Science Technology Office

Recent Updates to Earth Science Strategic Plan – Info Tech Impacts





Enable multiple measurements, from different sources and missions, to be effectively synthesized

Provide capabilities to combine data and models together to address the future evolution of the Earth system

Support scientific breakthroughs resulting from new observations and new ways of using those observations

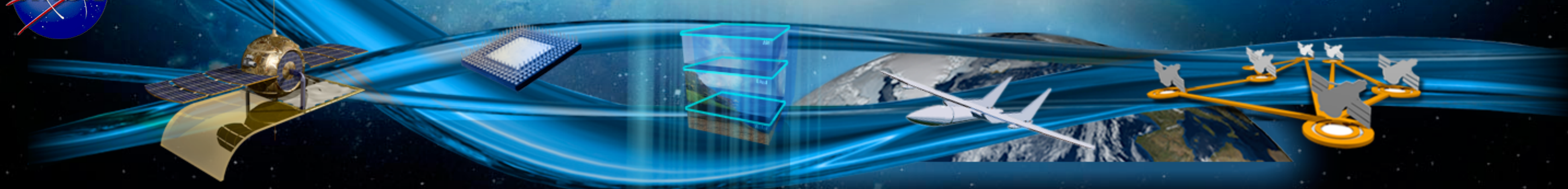
Provide methods for deriving data and information from multiple observations and sensors

Support use of data in models and data assimilation

Manage data and information to enable low cost distribution to users

Reduce the risk and cost of evolving NASA information systems to support future missions

Recent Focus Areas (from AIST-11)



Sensor Web Systems
Spacecraft operations & decision support
Tools for adaptive targeting
Management of sensor calibration across satellites
Sensor web technologies for science applications

Operations Management
Tools for reducing operational costs
New capabilities (e.g., near real-time operations, direct downlinks, autonomy)
On-board processing systems

Data Management Services
Scientific Workflows
Management of large simulation data
Discovery of science data services
Software architectures and frameworks

Advanced Data Processing
Tools for multi-source data fusion
Tools for data mining and visualization
Exploitation of graphical processing units (GPUs)
OSSE frameworks

Cyberinfrastructure
Tools to enable seamless research environments
Prototyping with cyberinfrastructure efforts (Earth Cube, NEX)
Exploitation of social media to share information

Proposals Help Identify Needs

The recent solicitations resulted in the following response from proposers, based on “natural” groupings

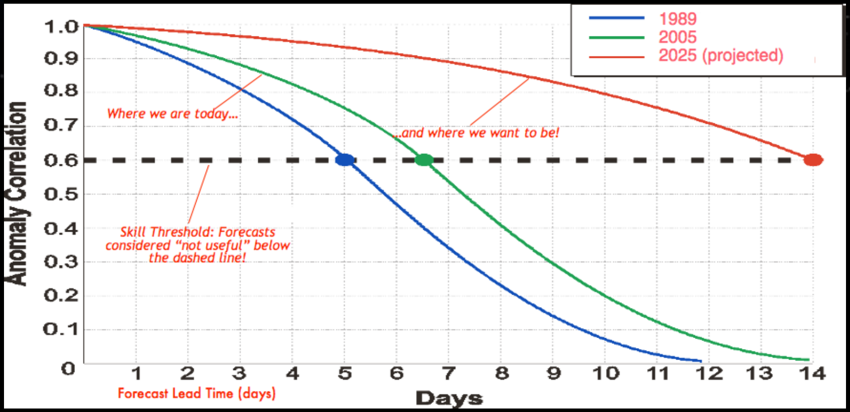
“Natural” Grouping (based on proposals)	Description
Adaptive / Collaborative Observing Technologies	Techniques to optimize data collection; e.g., one measurement changes the observing state of another
“Big Data” Projects	New techniques to analyze the voluminous Earth Science data anticipated over the next ten years
“Collaboratory” Projects	Information technologies to allow the sharing of analysis tools and data to support seamless scientific collaboration
Computational Technologies	New, high-performance algorithms for large scale science problems
High End Computing Technologies	New software technology to help scientists make the most effective use of high-end computing systems
Observing System Simulation Experiment (OSSE) Enablement	Tools to reduce the cost and risk of performing OSSEs
On Board Processing Projects	Hardware and software to enable the generation of low-latency data products

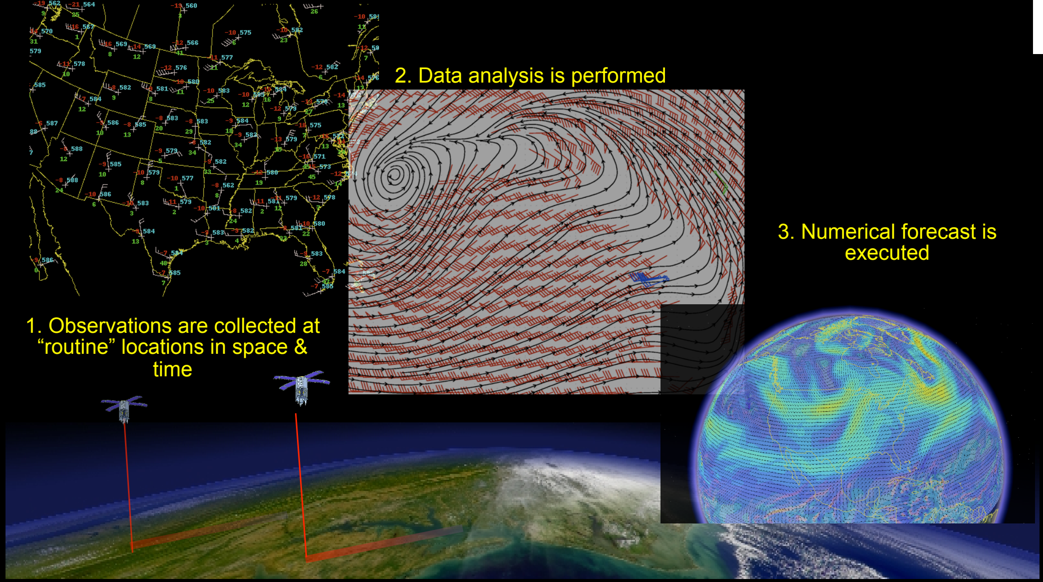
Sample Investments - Recent Projects

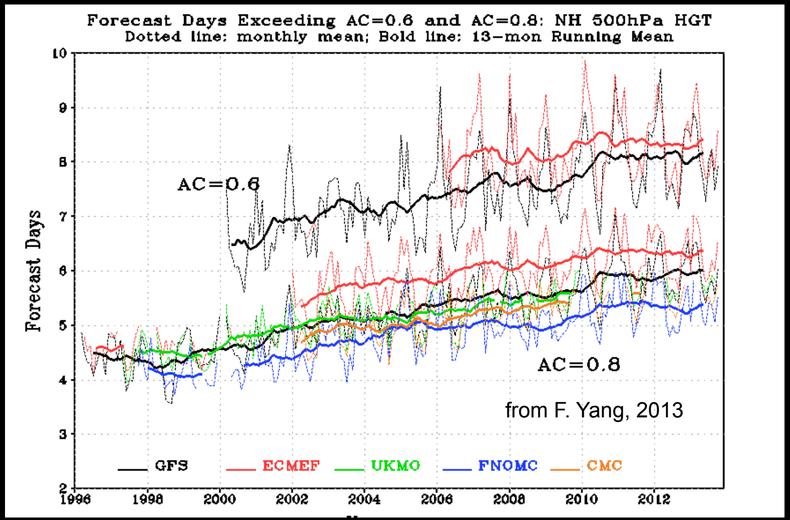
Sensor Webs for Improving Weather Prediction?

2006: Technology project launched to determine if sensor webs could provide a “revolutionary” improvement in the skill of numerical weather forecasts

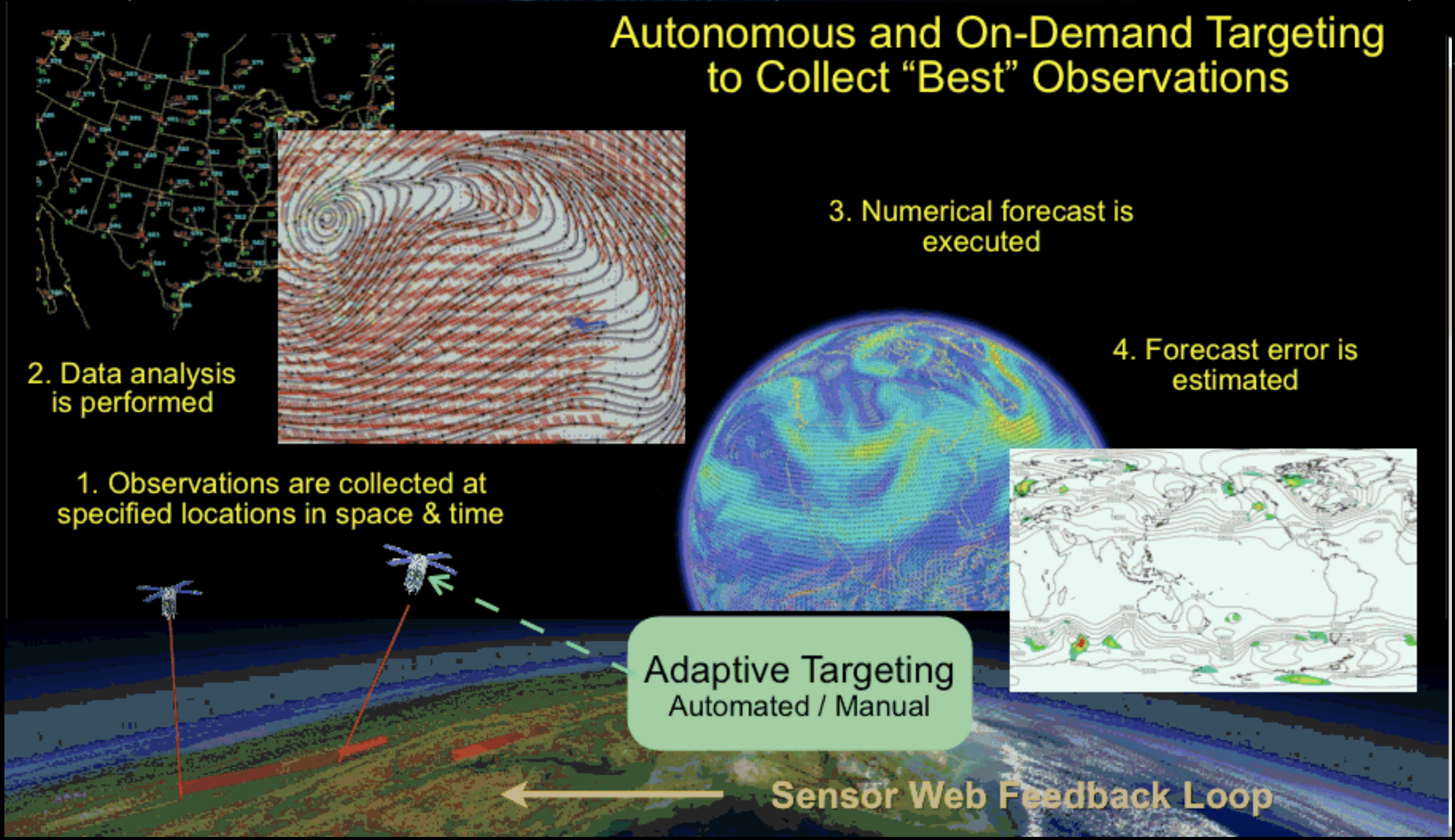
Could 7-day skill in 2005 improve to 14-day skill by 2025?







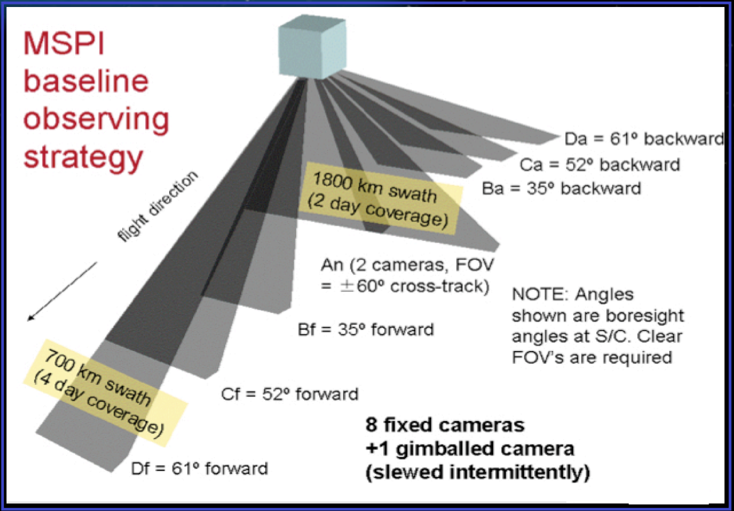
Example: Real-Time Data for Adaptive Targeting



COVE-2: CubeSat On-board Processing Validation Experiment

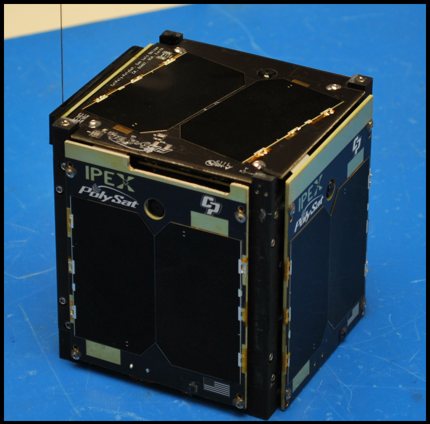
The Challenge

– Future missions will generate very high data volumes. For example, the Multi-angle Spectropolarimetric Imager (MSPI - Instrument Incubator Program, Diner/JPL), a candidate for the ACE mission, will produce 95 Megabytes per second per camera and there are nine cameras. There is currently no way to get that amount of data from space to the ground. Data reduction to 0.45 Mbytes/sec is required.



A Solution

– Move the first stage of ground processing on-board the satellite in a new radiation-hard-by-design FPGA. This would reduce downlink requirements by two orders of magnitude.



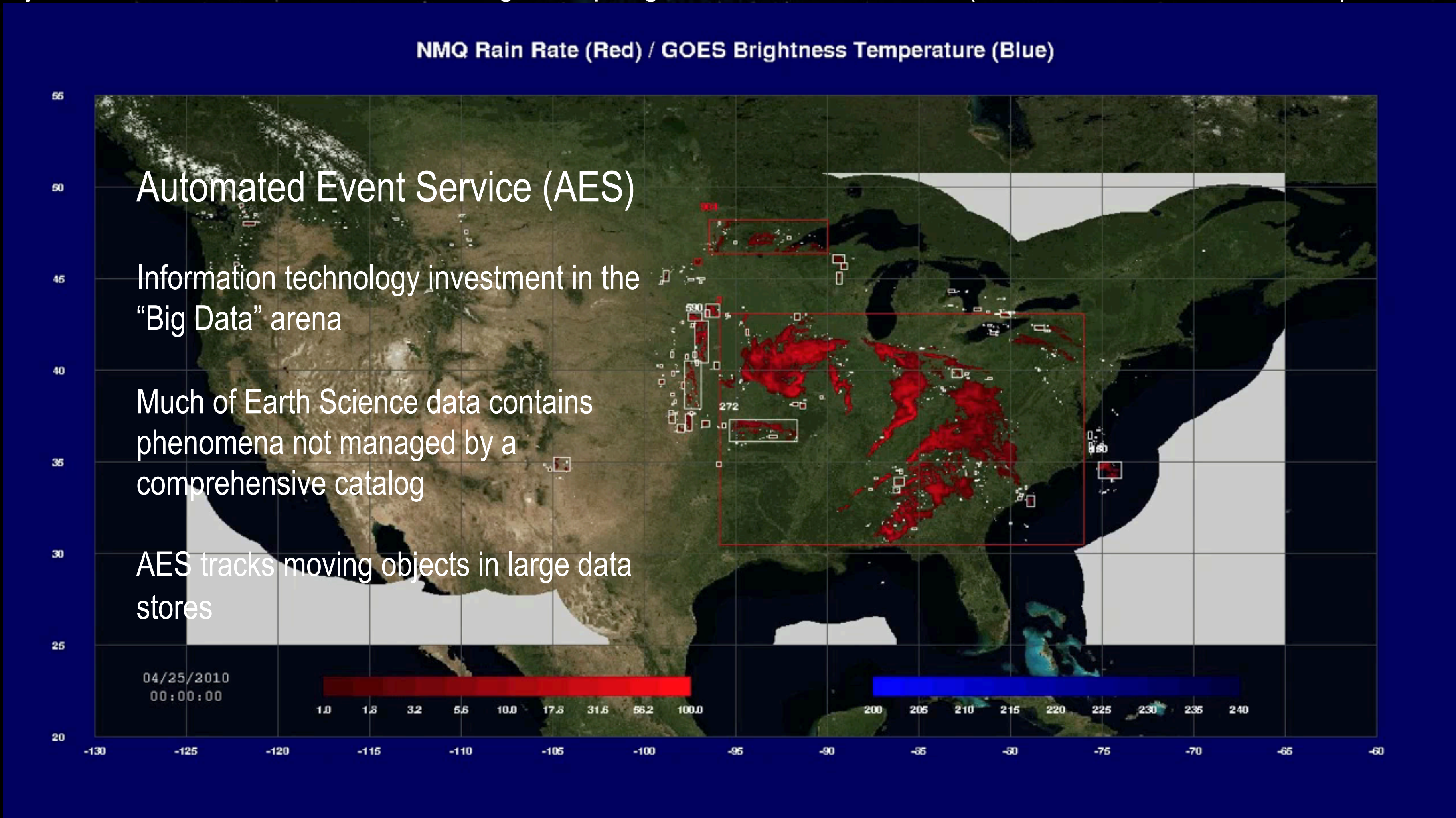
Progress!

– On Friday, Dec. 13th, 2013 beacon transmissions from the CubeSat successfully demonstrated first operation of COVE. This auto run sequence was scheduled for one week after deployment. System status is nominal as the team readies the spacecraft for full operational capability.

ESTO Earth Science Technology Office

Advanced Analytics: Automated Event Service

Example: FUSE data sources and MINE a multi-terabyte database for all occurrences of mesoscale convective systems over the United States during the Spring of 2010 - GSFC/SIVO (Tom Clune & Kwo-Sen Kuo)



Automated Event Service (AES)

Information technology investment in the "Big Data" arena

Much of Earth Science data contains phenomena not managed by a comprehensive catalog

AES tracks moving objects in large data stores

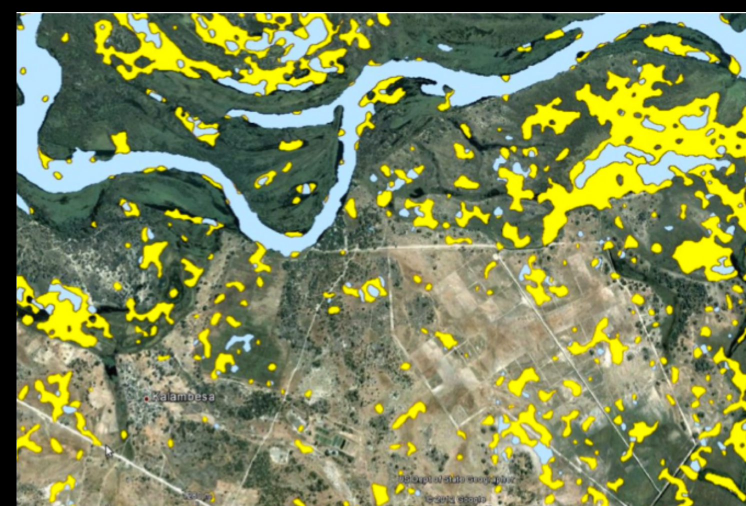
Info Systems Investments for Disasters

December 2010: Excessive rain with La Niña event produced widespread and persistent flooding

Little topographic relief - shallow flooding covers large expanses and is slow to drain

Kavango River in Namibia, Radarsat 2 image depicts open water (blue) and inundation (yellow).

Image processed manually by MacDonald Detweiller and Associates, derived from the image processing applied to 17 Feb 2012 Radarsat 2 image converted to KML and displayed in Google Earth.



Sample AIST Investment: Enhanced Mission Operations

Dan Mandl,
NASA Goddard Space Flight Center

Science User

Create, edit, test algorithms/classifiers for use on board

Custom algorithm

Machine learning supervised classifier (regression tree) - refined offline

Translator

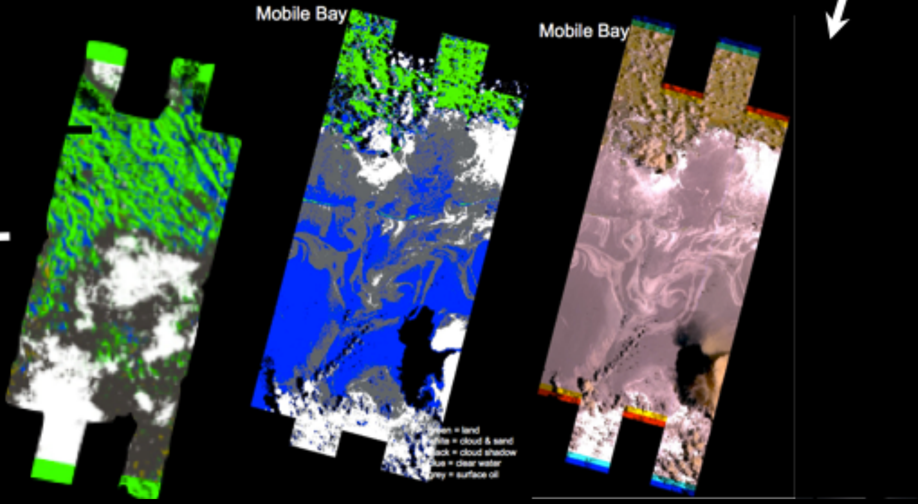
Web Coverage Processing Service (WCPS)

Quick algorithm upload

Allows uploads to various environments

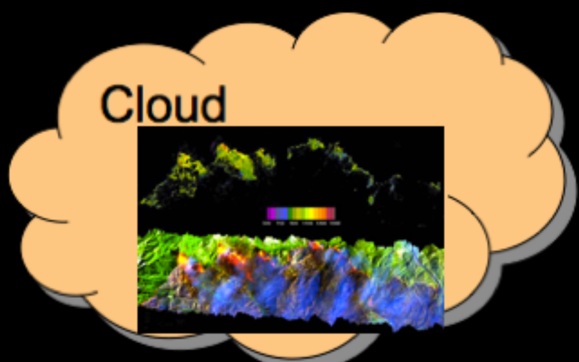
HyspIRI Intelligent Payload Module (IPM)

WCPS-Runtime executes algorithm for selected sensor data



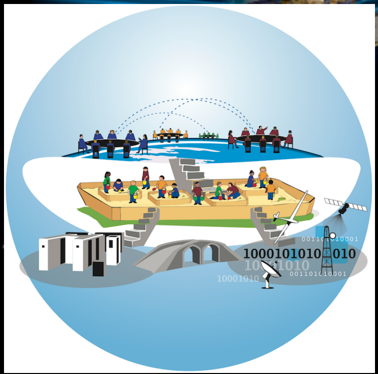
QuickLook data products

Notification to user



Sample AIST Investment: NASA Earth Exchange (NEX)

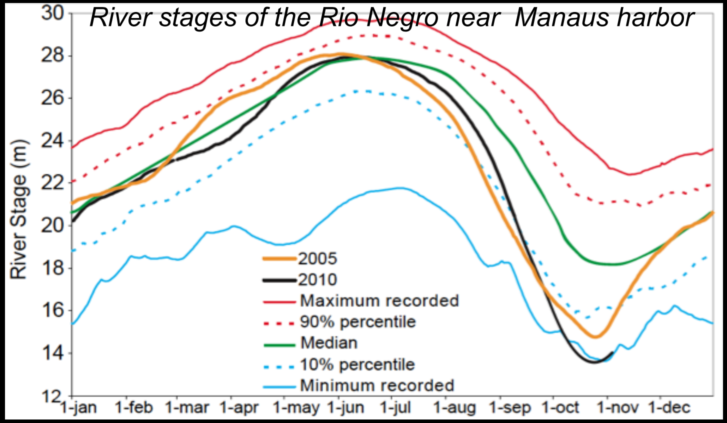
Rama Nemani, NASA / ARC
Rama Nemani, NASA / ARC

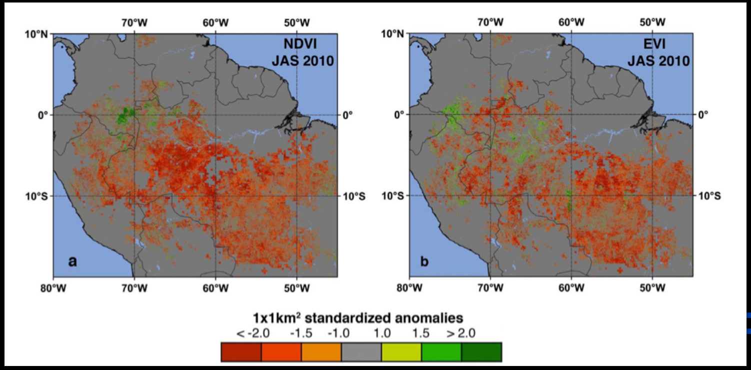


NASA's first Collaboratory brings computing and large data stores together to engage and enable the Earth science community address global environmental challenges

Current capability: 10K+ cores, 1PB online data

new paradigm in "big data" analysis and scientific discovery





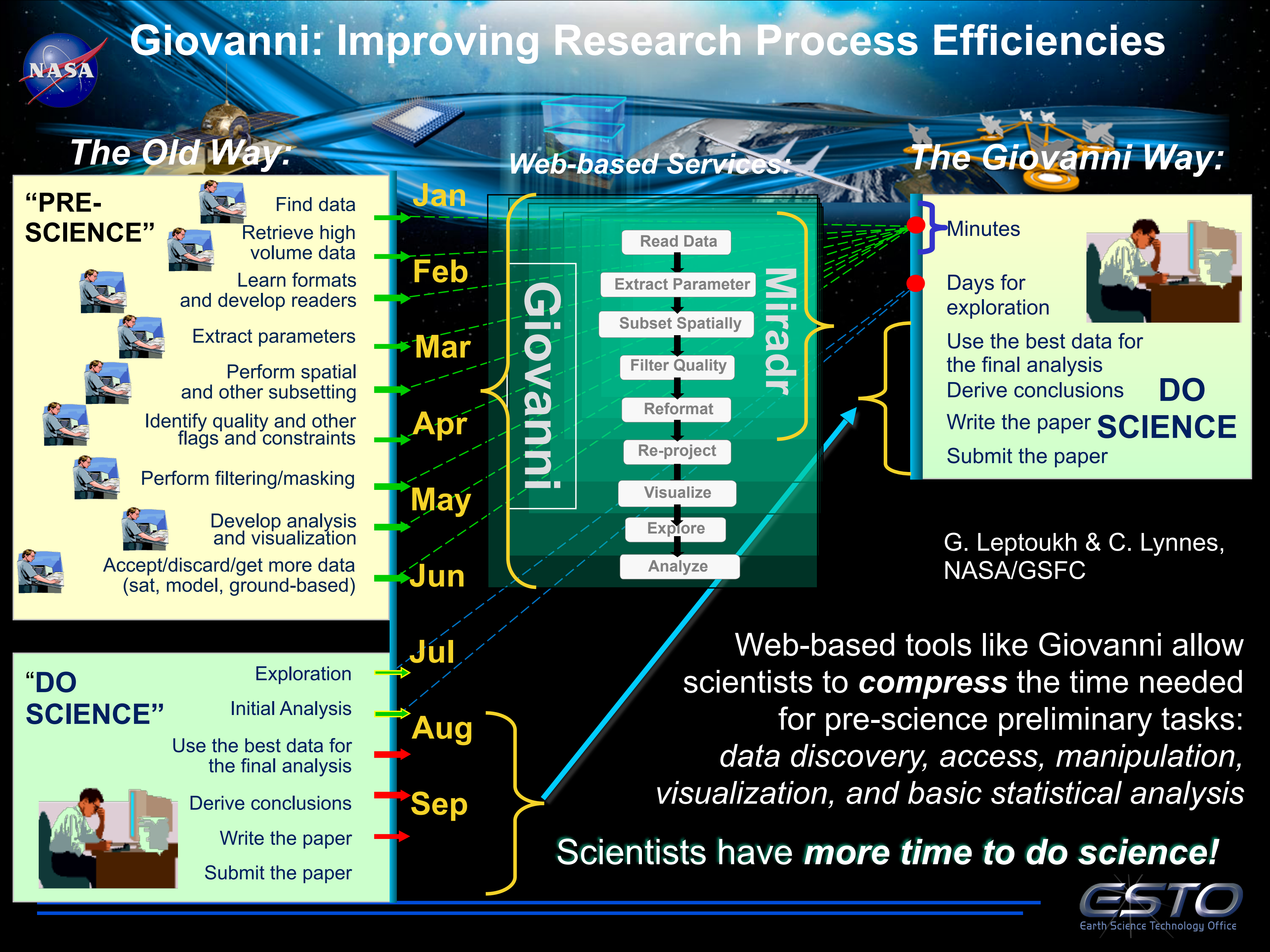
Samanta et al., 2010 and Xu et. al, 2011 used NEX to process large amounts of data to examine the 2005 and 2010 severe Amazon droughts

Prior to NEX (2005) case: 18 months to analyze data and submit paper
After NEX (2010 case): 4 months to analyze data and submit paper

Work begun in 2012 will build semi-automated workflows for science analysis

Primary funding for NEX is provided by NASA's High End Computing Program with support from ESTO

Earth Science Technology Office



Giovanni: Improving Research Process Efficiencies
NASA
The Old Way:
"PRE-SCIENCE"
Find data
Retrieve high volume data
Learn formats and develop readers
Extract parameters
Perform spatial and other subsetting
Identify quality and other flags and constraints
Perform filtering/masking
Develop analysis and visualization
Accept/discard/get more data (sat, model, ground-based)
"DO SCIENCE"
Exploration
Initial Analysis
Use the best data for the final analysis
Derive conclusions
Write the paper
Submit the paper
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Web-based Services:
Giovanni
Mirador
Read Data
Extract Parameter
Subset Spatially
Filter Quality
Reformat
Re-project
Visualize
Explore
Analyze
The Giovanni Way:
Minutes
Days for exploration
Use the best data for the final analysis
Derive conclusions
Write the paper
Submit the paper
DO SCIENCE
G. Leptoukh & C. Lynnes, NASA/GSFC
Web-based tools like Giovanni allow scientists to *compress* the time needed for pre-science preliminary tasks:
data discovery, access, manipulation, visualization, and basic statistical analysis
Scientists have *more time to do science!*
ESTO
Earth Science Technology Office

For More Information

GSFC Representatives to ESTO:

Bob Connerton (Robert.M.Connerton@nasa.gov)
301-614-5562 (Science & Missions)

Tom Grubb (Thomas.G.Grubb@nasa.gov)
301-286-9566 (Software & Info Systems)

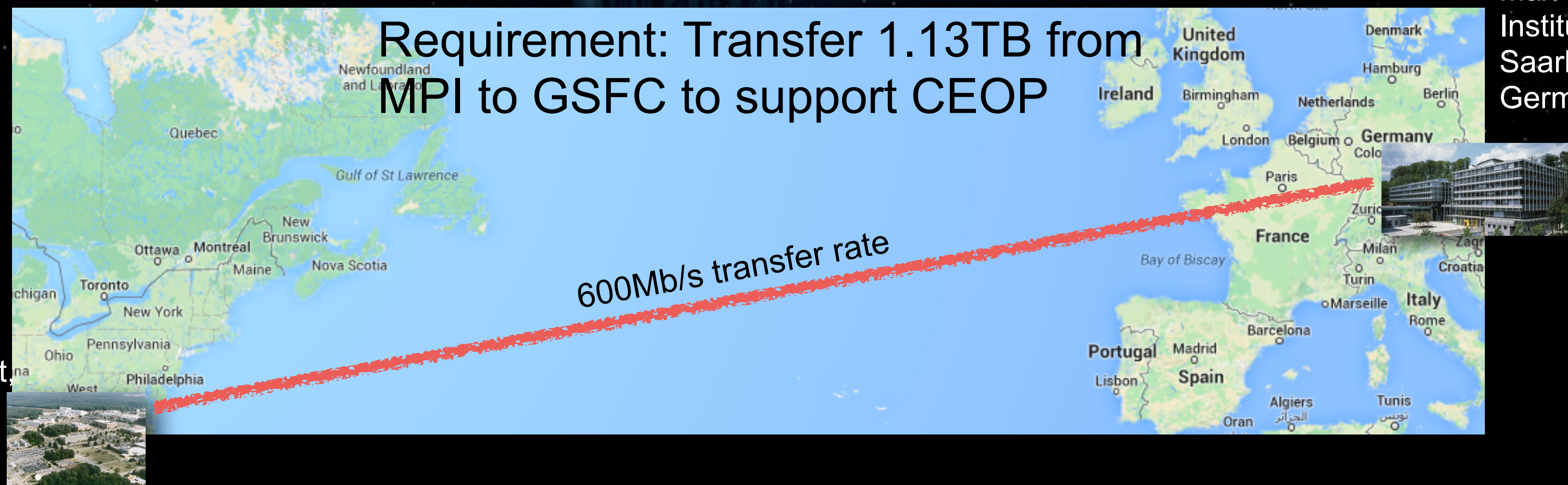
ESTO Staff

AIST Program Manager: Mike Seablom (Michael.S.Seablom@nasa.gov)
202-358-0442

CEOS & Sensor Web Systems: Karen Moe (Karen.Moe@nasa.gov) 301-286-2978

Big Data & Geospatial Systems: Marge Cole (Marjorie.C.Cole@nasa.gov

Impacts Due to (Typical) Inefficiencies



2007: Observations developed for the Coordinated Enhanced Observing Period (CEOP) required model output; 27 months of model data were contributed from 8 different institutions and were stored at the Max Planck Institute

Transfer of the needed 1.13TB should have taken about 8 hours with negligible labor

Transfer actually took 3 months with half an FTE of labor: unanticipated bottlenecks were encountered at both ends of the pipe

Such scenarios are *common*